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Nondestructive fault localization of multilayered semiconductor devices with frequency dependent ultrasound heating

多層構造をもつ半導体デバイスでの非破壊的な故障個所の絞込みにおける超音波加熱の周波数依存性

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1. Introduction

Three-dimensional integration (3DI) has been developed as an innovative technique to produce high-performance semiconductor devices. The devices produced by 3DI technique have a multilayered structure by stacking LSI chips.

As a nondestructive method to localize faults in semiconductor devices, the authors proposed ultrasound beam ineuced resistance change (SOBIRCH) method[1,2). Considering the 3DI technique, the SOBIRCH needs to deal with the localization of faults in the devices having a multilayered structure. The previous papers suggested that the ultrasound resonance inside semiconductor devices improves the signal intensity of SOBIRCH[3-5). This paper examined the possibility that the ultrasound resonance improves the signal intensity of SOBIRCH in a fault localization of the multilayered semiconductor devices.

2. System and Sample

Fig. 1 shows the schematic diagram of the system of SOBIRCH. Applying a bias voltage to a sample, the small current change generated by the ultrasound heating is detected as a SOBIRCH signal.

Fig. 2 illustrates the configuration of the sample. An aluminum wire whose width is 2 µm was deposited on a silicon bulk. On the wire, another silicon layer was stacked by using adhesive. The thickness of silicon and adhesive are 60 µm and 12µm. The aluminum wire was selected as observation target in this paper.

3. Experimental results

Fig. 3 shows SOBIRCH images with different ultrasound frequencies. The color bar of Fig. 3 denotes the intensity of SOBIRCH signal. The SOBIRCH signal showed the highest intensity at 70 MHz of ultrasound.

Fig. 4 shows the frequency dependence of SOBIRCH signal obtained from the experiment. The plots in Fig. 4 shows the experimental results of SOBIRCH signal. The dashed line in Fig. 4 shows the frequency dependence of the intensity of sound pressure calculated by the transfer matrix method[6,7). In the calculation, the mass density and speed of sound in silicon were 2330 kg/m^3 and 9400 m/s. The mass density and speed of sound in adhesive were 2750 kg/m^3 and 2200 m/s. Each series of experiment and calculation results is normalized to be each maximum as one. Fig. 4 suggests that the ultrasound resonance inside the multilayered structure improves the intensity of SOBIRCH signal.

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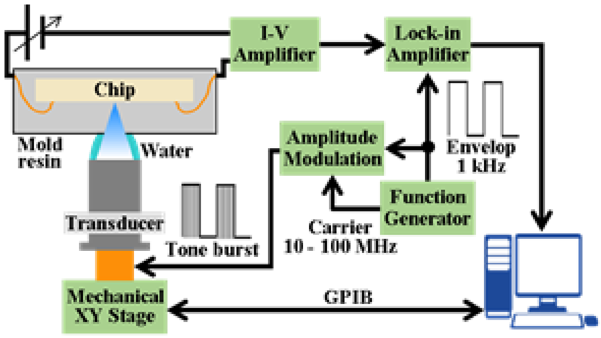

Fig. 1 System of SOBIRCH.

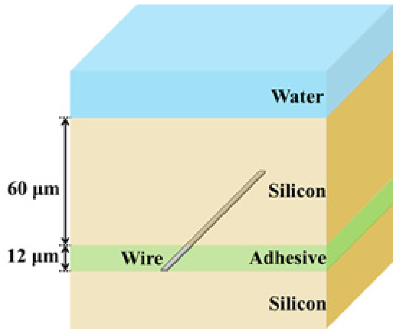

Fig. 2 Configuration of sample (wire width: 2 µm).

The difference between experiment and calculation results is based on an uncertainty of the thickness of adhesive. An error of several µm in thickness of adhesive makes a big effect to the resonant frequency since the adhesive is too thin. Considering the uncertainty of the thickness of adhesive, the difference between experiment and calculation results is acceptable.

The resonant frequency of silicon with 9400 m/s of speed of sound and 60 µm of thickness was about 79 MHz. The resonant frequency of adhesive with 2200 m/s of speed of sound and 12 µm of thickness was 90 MHz. The assumption that the resonance in silicon or the resonance in adhesive make an effect to the frequency dependence of SOBIRCH signal, dose not well explain that the experimental results showed a highest intensity in the vicinity of 70 MHz of ultrasound.

4. Discussion

The transfer matrix method can be applied to the calculation without anything deep consideration on the phenomena of multiple reflection inside the multilayered structure. On the other hand, the transfer matrix method cannot clarify what components the frequency dependence of ultrasound consists of. This section will examine the components of the frequency dependence of SOBIRH signal by analytical approach

Fig. 5 shows the simplified model of Fig. 2. We assumed that a plane wave is vertically incident on medium 2 from medium 3. In Fig. 5, γ_a and $L_a$represent the propagation constant and the thickness of the medium a, respectively. $p_{a,b}$ represents an ultrasound wave incident on medium a from medium b. The formula of input-output relation of ultrasound in arbitrary medium n is defined as eq. (1).

$$\begin{cases} p_{n-1,n} = t_{n-1,n} x_n H_n p_{n,n+1} + \dfrac{t_{n-1,n}}{r_{n-1,n}} (H_n - 1) p_{n,n-1}, \\ p_{n+1,n} = \dfrac{t_{n+1,n}}{r_{n+1,n}} (H_n - 1) p_{n,n+1} + t_{n+1,n} x_n H_n p_{n,n-1}. \end{cases} \quad (1)$$

In eq. (1), $t_{a,b}$ and $r_{a,b}$ are the transmittance and reflectance of sound pressure when a plane wave is incident on medium a from medium b. x_n and H_n in eq. (1) are defined as eq. (2).

$$x_n = r_{n+1,n} r_{n-1,n} e^{-i\gamma_n L_n}, H_n = \frac{1}{1 - x_n^2}. \quad (2)$$

H_n represents the resonance of ultrasound in medium n. The formula of the relation between $p_{0,1}$ and p_{in}^{+} is derived as eq. (3) assuming that $p_{in}^{-} = p_{1,0} = 0$ and $p_{2,3} = t_{2,3} p_{in}^{+}$ in Fig. 5.

$$p_{0,1} = t_{0,1} t_{1,2} t_{2,3} x_1 x_2 H_1 H_2 H_{1,2} p_{in}^{+}. \quad (3)$$

In eq. (3), $H_{1,2}$ becomes a function shown in eq. (4).

$$H_{1,2} = \frac{1}{1 - \dfrac{t_{1,2} t_{2,1}}{r_{1,2} r_{2,1}} (H_1 - 1)(H_2 - 1)}. \quad (4)$$

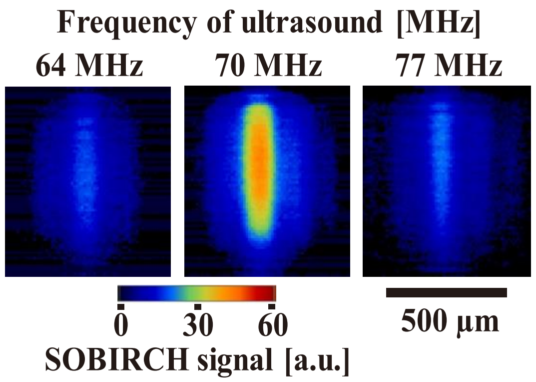

Fig. 3 SOBIRCH images with different frequencies.

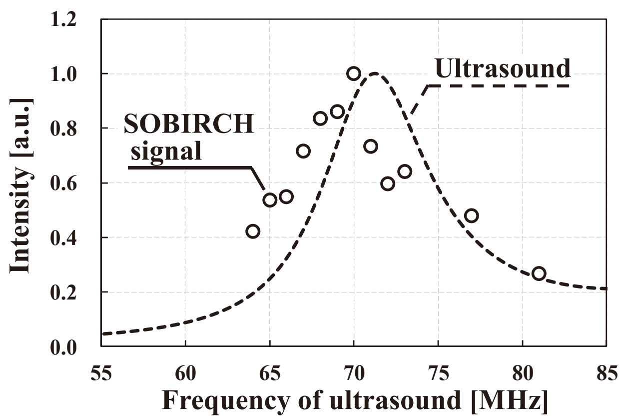

Fig. 4 Frequency dependence of SOBIRCH signal.

$H_{1,2}$ is equal to $H_{\mathrm{Ad,Si}}$. $H_{\mathrm{Ad,Si}}$ represents the resonance across adhesive and silicon. From eq. (3), it is found that the frequency characteristics of $p_{0,1}$ consists of not only the resonance in adhesive and the resonance in silicon but also the resonance across adhesive and silicon. Fig. 6 shows the frequency characteristics of $|H_{\mathrm{Ad}}|, |H_{\mathrm{Si}}|$ and $|H_{\mathrm{Ad,Si}}|$. In the calculation of Fig. 6, the same acoustic parameters as Fig. 4 were used. $|H_{Ad,\mathrm{Si}}|$ shows a peak in the vicinity of 70 MHz. Fig. 6 suggests that the ultrasound resonance across silicon and adhesive dominates the frequency dependence of SOBIRCH signal.

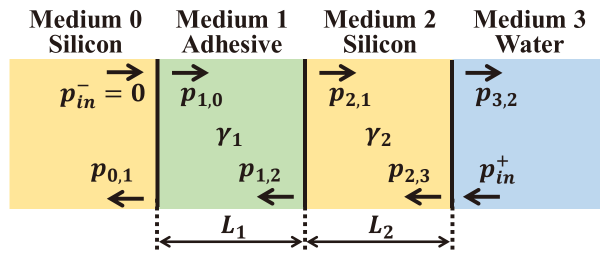

Fig. 5 Analysis model of ultrasound resonance

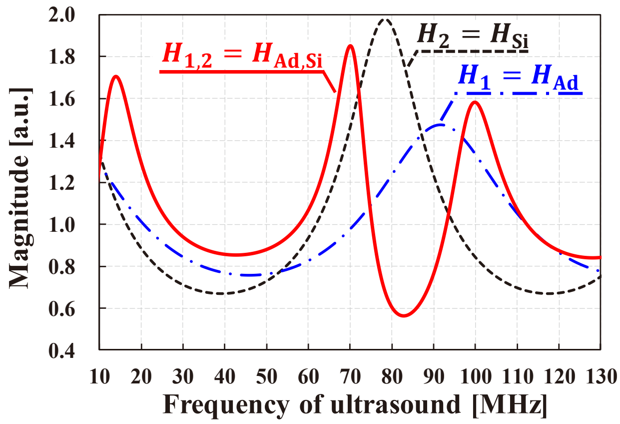

Fig. 6 Frequency characteristics of $|H_{Ad}|, |H_{Si}|, |H_{\mathrm{Ad,Si}}|$

5. Conclusion

This paper examined the frequency dependence of SOBIRCH signal in the sample having a multilayered structure. The experimental result suggested that the resonance of ultrasound improves the intensity of SOBIRCH signal in fault localization of semiconductor devices having a multilayered structure by appropriately tuning ultrasound frequency. The analytical solution suggested that the ultrasound resonance across silicon and adhesive dominates the frequency dependence of SOBIRCH signal.

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